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MULTIVARIATE ANALYSIS OF THE VARIABILITY IN THE DENSITY OF OVEN-DRY WOOD OF SILVER BIRCH (*BETULA PENDULA* ROTH.) IN POLAND

This work presents the findings of a study concerning the variability in the density of oven-dry silver birch wood, depending on the geographical placement of tree stands, of the age and thickness of the trees, the influence of the forest habitat type and interactions occurring between chosen factors. The study was carried out on wood from trees aged approx. 30, 50 and 70 years old in 12 forest districts located throughout Poland. Altogether 4777 wood samples taken from 306 trees acquired on 51 test plots were measured. A significant influence of all the examined factors on the variability of the density of the oven-dry wood of the silver birch was proven. The highest mean values of the density of the birch wood in an oven-dry state were found in the Forest District of Giżycko in fresh mixed broadleaved forests – 669,85 kg/m^3 and in the Forest District of Sokołów in fresh broadleaved forests – 662,04 kg/m^3. For the entire examined material, mean values of the density of oven-dry wood are increasing along with age. In all three of the examined tree ages, the highest mean values were noted in the thinnest trees.

Keywords: age of trees, forest habitat type, thickness of trees, geographical situation, technical quality of wood, physical properties of wood

Introduction

In Polish forests, the share of broadleaved tree species, including silver birch, is on the rise. The natural reaches of the Polish main forest forming tree species are also undergoing changes. The changes on the market of the raw wood material in Europe and in Poland, force the forest sector to conduct the monitoring of the wood market in innovative ways and to analyse the changes in technologies of the processing of woody raw material as well as the directions of its future uses. The increase of the supply of wood from broadleaved trees on the European and Polish markets is caused by, amongst other things, progressive global warming.

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It particularly concerns the wood of silver birch, regarded in the central and northeast part of Europe as one of the most important and most promising types of wood for further processing and application both in the wood industry, as well as the energy sector [Lachowicz 2015b]. Because of economic transformations that occurred in Poland at the beginning of 90's, in many places the agricultural use of land has ceased due to low profitability of the production there. In many cases in these areas, by way of secondary succession, silver birch forest stands have formed. Because of the effects of these processes in the last 10 to 20 years, a significant increase in the birch stands coverage has been observed. Those stands will, in a few decades, become an essential part of the birch wood resource base [Bijak et al. 2014; Zasada et al. 2014].

Density is the basic and most often determined property of wood which indeed influences its fundamental physical, mechanical and technological properties [Kokociński 2004]. Examples of findings in the density of wood in conjunction with structural and mechanical properties for various species of trees conducted in accordance with different methodological approaches can be found in literature on the subject [Tomczak and Jelonek 2012; Wąsik et al. 2015]. Published results of the birch wood density largely concern the wood in an air-dry state (moisture content 12 or 15%) or basic density [Hakkila 1966; Hakkila 1979; Helińska-Raczkowska and Fabisiak 1995; Helińska-Raczkowska 1996; Fabisiak 2005; Fabisiak and Kocjan 2005; Möttönen and Luostarinen 2006; Repola 2006; Lachowicz 2015b; Wroniszewska 2015].

The analysis of the results of the foreign and Polish studies concerning the technical quality of birch wood, show that these studies were based on unknown criteria to select study materials [Vorreiter 1949; Kollmann 1951; Wanin 1953; Trendelenburg and Mayer-Weglin 1955, Galewski and Korzeniowski 1958; Kamiński and Laurow 1966; Miler 1961; Miler 1966; Krzysik 1978; Wagenführ and Scheiber 2007]. Thus far, in Poland, there were no comprehensive studies drawn up according to a uniform methodology which would concentrate on the relations between geographical situation, age of trees, thickness of trees and the habitat type of forest, and the technical quality of the birch wood.

From 2003 to 2007, in northeast Poland pilot scheme studies were conducted which constituted an extensive introduction to current studies of the technical quality of silver birch wood in accordance with the same methodology as in the rest of Poland. Their completion means a unique database of one of the prime forest forming tree species in Poland was created, as well as the north and eastern part of Europe, which contains information, (the widest so far) about the values of individual properties of birch wood [Lachowicz 2015a; Lachowicz 2015b].

This knowledge and the cognition of certain, so far not studied phenomena concerning wood structure, can be useful not only for conducting scientific and technological examinations, but also will have a noteworthy influence on further rational, economic uses and in the implementation of innovative wood applications of this tree species, of which there is still relatively little knowledge of. The results obtained and the analysis of the examined properties of wood, including proven interdependence occurring between the location of tree stands, the age of trees, their thickness, the forest habitat type and parameters of the technical quality of the wood of the silver birch should provide significant support in the creation of the State Forest's marketing strategy.

The aim of this study is to examine the variability of the density of the wood of the silver birch in an oven-dry state depending on the location (of the geographical situation) of tree stands, the age of trees, the thickness of trees, the type of habitat forest and interactions occurring between the chosen factors.

Materials and methods

The methodology of field works was based on the past experiences from earlier conducted studies concerning the technical quality of silver birch wood in northeast Poland [Lachowicz 2010a; Lachowicz 2010b; Lachowicz et al. 2014; Lachowicz and Paschalis-Jakubowicz 2014].

The area of forests under the administration of the State Forests according to habitat types of forest for birch as a dominant tree species amounted to: 80344.53 ha in fresh broadleaved forests, 77239.53 ha in fresh mixed broadleaved forests, 44794.20 ha in moist mixed broadleaved forests and 35014.86 ha in fresh mixed coniferous forests. The merchantable volume of forests under the administration of the State Forests according to habitat types of forest for birch as a dominant tree species amounted to: 19849930 m^3 in fresh broadleaved forests, 17130048 m^3 in fresh mixed broadleaved forests, 9233238 m^3 in moist mixed broadleaved forests and 6092664 m^3 in fresh mixed coniferous forests.

This study was conducted on the forest stands under the administration of the State Forests National Forest Holding (PGL LP). Based on the data from the Bureau for Forest Management and Geodesy obtained in the form of tables of area and merchantable volume (dated 1st of January 2012) and of geographical placement of forest districts in principal resource bases of birch, forest districts which fulfilled the methodological criterion concerning the establishments of test plots were chosen. The stands with birch trees of approx. 30, 50 and 70 years of age were chosen, in fresh broadleaved forest habitats (FBF) and fresh mixed broadleaved forest habitats (FMBF). Those are the two types of habitat where birch forest stands in Poland dominate in size and volume above all other forest habitat types.

Forest habitat type (FHT) is a fundamental unit in the classification system of forest habitats, that covers forest areas of similar habitat conditions resulting from the fertility and the humidity of the soil, the similitude of climate and landform features and its geological structure. The areas belonging to the same forest habitat type are showing similar production capacity and silviculture

[Forest Data Bank 2017]. In this work studies were conducted in the fresh broadleaved forest (FBF) and fresh mixed broadleaved forest (FMBF) habitat types. Fresh broadleaved forest (FBF) is a lowland forest habitat type (FHT) and it covers very fertile and fresh forest habitats. It is found on sites with brown soil, mainly leach, sometimes acidic or proper brown soil, proper lessive, with mull type humus or the typical mull. Fresh mixed broadleaved forest (FMBF) is a lowland forest habitat type (FHT) it covers fresh habitats of average fertility. It is found on brown leach, podzol or acidic soils, proper fawn soils, spodic, sometimes on podzoluvisols, proper podzol or rusty soils most of the time with typical humus.

Fig. 1. Geographical layout of the Forests Districts where the test plots were located

Field studies were conducted in 12 Forest Districts spaced throughout Poland in 3 tree age variations of approx. 30, 50 and 70 years old in the following forest habitat types: Płońsk (FBF), Sokołów (FBF), Biała Podlaska (FBF), Płaska (FBF), Górowo Iławeckie (FBF), Elbląg (FBF), Mircze (FBF), Giżycko (FBF and FMBF), Bobolice (FBF and FMBF), Łobez (FBF and FMBF), Lipinki (FBF and FMBF), Rudziniec (FBF and FMBF) (fig. 1). The age of trees in each age class varied between: 30 (26- -33), 50 (40-53), 70 (66-72) years old. The choice of forest stands, in which the test plots were to be established was preceded by the cross referencing of inventory notes found in the District's offices against the actual state of stands found on the site. The superior quality of lumber in the selected forest stands allowed for the preparation of the wood samples for further analysis. In total, the samples were obtained from 51 test plots (including material from the 12 plots that were used in the pilot scheme studies conducted in northeast Poland). Shortened inventory descriptions of all forest stands were placed in the wider publications concerning the quality of the birch lumber material in Poland [Lachowicz 2015a; Lachowicz 2015b].

On the test plots, the diameters of all trees of above 7 cm at breast height were measured. The sample trees on the test plots were chosen using Hartig's method based on the mean DBH area with 3 thickness classes [Grochowski 1973]: class 1 – the trees with low DBH, 2 – the trees with average DBH, 3 – the trees with high DBH.

From within each thickness class, 2 trees with DBH amounted to the mean DBH area in the class were chosen and felled, which makes 6 trees from each sample plot. In total sample materials were collected from 306 trees. Two or three 50-centimetre-long trunk sections were cut out (below 1.3 metres height point and 50-100 cm above it) then split open and marked appropriately. After seasoning, when the wood moisture content reached the level of approximately 15%, the samples were formed for analysis of the studied properties. Samples were collected and prepared in accordance with Polish Standards [PN-77/D--04227]. The density of the oven-dry wood was determined using block samples that measured 20 × 20 × 30 mm (where the third measurement is taken in a longitudinal direction) as per Polish Standards [PN-77/D-04101]. The stereometrics measurements (in radial, tangential and longitudinal directions) were taken using an electronic calliper with up to 0.01 mm accuracy level. Weight was obtained with a technical weighing scales with an accuracy level of 0.001 g. The moisture content of the samples was measured in accordance with Polish Standards [PN-77/D-04100]. The density of the silver birch wood in an oven-dry state was determined for 4777 samples with the use of the following formulae:

$$g_0 = \frac{m_0}{V_0}$$

g_0 – density of oven-dry wood [kg/m^3]
m_0 – mass of oven-dry wood [kg]
V_0 – volume of oven-dry wood [m^3]

Due to the wide spectrum of analyses and the sheer number of samples collected, it became necessary to adopt an appropriate statistical method that would allow a credible evaluation of regularities appearing in the properties of birch wood representing different research subjects [Bruchwald 1989; Stanisz 2006; Kala 2009].

The results obtained were subjected to a statistical analysis, enabling the determination of the influence of the location, the age of trees, the class of the thickness of trees and the habitat type on mean values of the density of oven-dry wood.

For this purpose, a two-way anova was used. The analysis of means was carried out with the use of Tukey's studentized range test. The significance of the differences was evaluated by HSD (Honestly Significant Difference) calculated for the confidence level of 95%.

Results and discussion

The oven-dry birch wood density properties were calculated in relation to the location, tree age and the forest habitat type with the addition of the total values of those properties for the complete set of data (tab. 1).

Table 1. The oven-dry birch wood density properties [kg/m^3] in relation to the location and the age of the trees

Location – Forestry District	Tree age	Number of groups (N)	Mean	Minimum	Maximum
1 Płońsk FBF	30	80	618.08	490.6	744.4
	50	89	654.33	511.0	781.5
	70	96	661.62	576.6	744.4
	Total	265	646.03	490.6	781.5
2 Sokołów FBF	30	93	659.98	529.1	762.4
	50	96	676.88	552.5	766.9
	70	96	649.20	528.6	746.6
	Total	285	662.04	528.6	766.9
3 Biała Podlaska FBF	30	87	617.25	507.6	706.4
	50	96	670.03	567.9	808.5
	70	90	654.31	568.5	735.7
	Total	273	648.03	507.6	808.5
4 Płaska FBF	30	93	622.56	536.9	723.9
	50	96	605.77	511.0	746.4
	70	96	626.72	537.7	741.3
	Total	285	618.31	511.0	746.4

Location – Forestry District	Tree age	Number of groups (N)	Mean	Minimum	Maximum
5 Giżycko FBF	30	96	621.50	518.2	695.7
	50	55	624.56	523.5	816.7
	70	96	658.06	573.2	757.1
	Total	247	636.39	518.2	816.7
6 Giżycko FMBF	30	96	638.41	519.3	778.5
	50	96	679.03	553.3	780.2
	70	96	692.10	618.8	772.7
	Total	288	669.85	519.3	780.2
7 Górowo Iławeckie FBF	30	96	601.13	528.8	678.1
	50	96	624.46	487.1	730.3
	70	94	654.76	525.7	758.2
	Total	286	626.59	487.1	758.2
8 Elbląg FBF	30	96	613.57	478.9	750.1
	50	96	612.50	551.8	689.8
	70	96	630.29	513.4	774.6
	Total	288	618.79	478.9	774.6
9 Mircze FBF	30	96	630.44	531.6	702.8
	50	96	649.76	522.8	751.8
	70	96	635.22	570.1	778.1
	Total	288	638.48	522.8	778.1
10 Bobolice FBF	30	95	601.42	472.5	680.8
	50	96	627.88	528.3	729.1
	70	96	634.72	588.7	709.2
	Total	287	621.41	472.5	729.1
11 Bobolice FMBF	30	90	614.86	545.3	682.1
	50	95	594.69	462.6	689.0
	70	95	640.01	510.8	729.8
	Total	280	616.55	462.6	729.8
12 Łobez FBF	30	87	566.37	467.8	669.5
	50	96	657.98	532.2	777.1
	70	96	671.74	600.0	813.3
	Total	279	634.15	467.8	813.3

Location – Forestry District	Tree age	Number of groups (N)	Mean	Minimum	Maximum
13 Łobez FMBF	30	91	579.98	490.0	650.9
	50	96	607.48	553.8	683.8
	70	96	646.51	577.3	721.9
	Total	283	611.88	490.0	721.9
14 Lipinki FBF	30	89	595.35	504.5	677.5
	50	96	631.96	555.6	763.5
	70	96	650.17	583.9	740.6
	Total	281	626.58	504.5	763.5
15 Lipinki FMBF	30	95	590.61	460.0	687.8
	50	96	646.16	529.1	737.9
	70	96	674.47	579.0	765.6
	Total	287	637.24	460.0	765.6
16 Rudziniec FBF	30	96	590.21	519.0	715.8
	50	96	626.20	519.5	757.7
	70	96	634.61	582.5	721.4
	Total	288	617.01	519.0	757.7
17 Rudziniec FMBF	30	95	643.43	527.0	763.3
	50	96	625.76	485.2	743.0
	70	96	665.05	585.3	810.8
	Total	287	644.75	485.2	810.8
FBF		3352	632.62	467.8	816.7
FMBF		1425	636.24	460.0	810.8
Age 30		1571	612.29	460.0	778.5
Age 50		1583	636.45	462.6	816.7
Age 70		1623	651.73	510.8	813.3
Total		4777	633.70	460.0	816.7

The lowest mean value of density of the oven-dry birch wood in relation to the age of the tree – 566.37 kg/m^3 was registered for 30-year-old birch trees in the Łobez District in an FBF habitat, the highest – 692.10 kg/m^3 for 70-year-old birch trees that grew in a FMBF habitat type forest in the Giżycko District.

The lowest mean value of density of the oven-dry birch wood in relation to geographical location was found in the Łobez District in an FBF habitat and was calculated to be – 611.88 kg/m^3 while the highest – 669.85 kg/m^3 was found in the Giżycko District in a FMBF habitat type forest. A rise of 9.47% was observed.

The average values of density for the complete set of analysed data in relation to forest habitat types differed from each other slightly, reaching 632.62 kg/m^3 in an FBF habitat type and 636.24 kg/m^3 in an FMBF habitat type.

The rise of oven-dry wood density values was noted in relation to the age of the trees. The lowest average density values were found in 30-year-old trees – 612.29 kg/m^3, higher in 50-year-old trees – 636.45 kg/m^3 and the highest in 70--year-old birch trees – 651.73 kg/m^3.

The mean density of oven-dry silver birch wood for the entire analysed material amounted to 633.70 kg/m^3. The lowest density of a single test sample determined in the analysed material was 460,0 kg/m^3 and it originated from 30--year-old birch trees growing in fresh mixed broadleaved forest type habitats and the highest – 816.7 kg/m^3 from 50-year-old trees in a fresh broadleaved forest type habitat.

It was shown that the geographical location of the test plots and the age of the trees as well as interactions between them generated statistically significant differences in the studied material, in the average values of wood density in the analysed groups (tab. 2).

Table 2. Influence of the location and the age of trees and interaction of these properties on the density of oven-dry wood (two factorial variance analysis)

Source of variance	Sum of squares	Degrees of freedom	Mean squares	F empirical	p-Value
Intercept	1902807838.3	1	1902807838.3	856312.6	< 0.0001 *
Location	1241894.0	16	77618.4	34.9	< 0.0001 *
Age	1271117.5	2	635558.8	286.0	< 0.0001 *
Location-Age (interaction)	1054873.2	32	32964.8	14.8	< 0.0001 *
Error	10501620.8	4726	2222.1		

*Statistically significant at the 0.05 level.

The columns of table 3 show the groups of locations that did not display statistically significant differences in the values of wood density. Forest Districts where trees of the lowest values of mean density of oven-dry wood are growing, whilst at the same time not differing significantly between each other are: Łobez (FMBF), Bobolice (FMBF and FBF), Rudziniec (FBF), Płaska, Elbląg, Lipinki (FBF) and Górowo Iławeckie. The highest wood density values were found in the District of Giżycko in FMBF and Sokołów in FBF.

The comparison of oven-dry wood density values between different tree ages has shown statistically significant differences between all groups. The average values of the studied properties rise with age (fig. 2).

Table 3. Groups of homogeneous locations in terms of the mean density values of oven-dry wood

Location	Mean	1	2	3	4	5	6
Łobez – FMBF	611.88	****					
Bobolice – FMBF	616.55	****					
Rudziniec – FBF	617.01	****					
Płaska – FBF	618.31	****					
Elbląg – FBF	618.79	****					
Bobolice – FBF	621.41	****	****				
Lipinki – FBF	626.58	****	****	****			
Górowo Iławeckie – FBF	626.59	****	****	****			
Łobez – FBF	634.15		****	****	****		
Giżycko – FBF	636.39		****	****	****		
Lipinki – FMBF	637.24			****	****		
Mircze – FBF	638.48			****	****		
Rudziniec – FMBF	644.75				****		
Płońsk – FBF	646.03				****		
Biała Podlaska – FBF	648.03				****	****	
Sokołów – FBF	662.04					****	****
Giżycko – FMBF	669.85						****

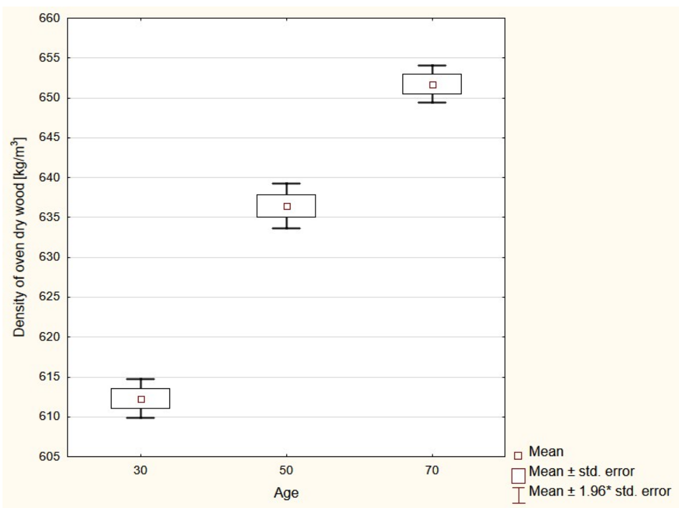

Fig. 2. Mean values of oven-dry wood density in different tree ages

Analysis of the relation between the density of oven-dry wood, and the location of the test plots and the age, demonstrated the existence of homogeneous groups of a very complicated nature for which it is hard to show a general rule (fig. 3). In the forest districts of Płońsk, Płaska, Giżycko in FBF and FMBF habitats, Górowo Iławeckie, Elbląg and Bobolice, Łobez, Lipinki and Rudziniec, on both studied forest type habitats the highest mean density was noted for the oldest trees – 70-year-old. Among those mentioned in the Forest Districts of Płaska, Elbląg, Bobolice in FMBF and Rudziniec FMBF higher mean density in the wood from 30-year-old trees in comparison to the wood from 50-year-old birch trees were noted. Forest Districts where the highest density of oven-dry wood from 50-year-old trees was found are: Sokołów, Biała Podlaska i Mircze. Among these, in the District of Sokołów, the lowest mean density was noted for the wood from 70-year-old trees and, in the District of Biała Podlaska and Mircze, for wood from 30-year-old trees.

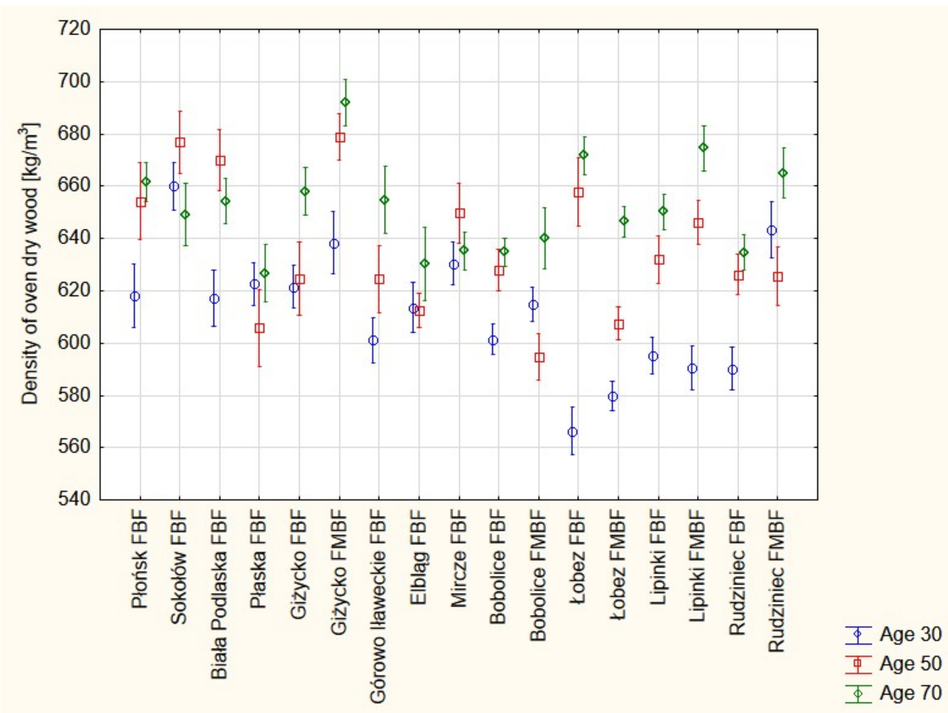

Fig. 3. The average values of oven-dry wood density and their standard errors in relation to the location and age

The analysis of the correlation between the value of oven-dry wood density and the age of trees, thickness class and interactions between these factors demonstrated that statistically significant differences exist between the average values of the analysed properties (tab. 4). Only in the case of the youngest trees was no correlation noted between the thickness class and the density of oven-dry wood. The values of wood density differed along with the age and, in the oldest analysed trees, the average density values for the samples representing each thickness class shows statistically significant differences between each other. The statistics characterising wood density divided in to thickness classes in relation to age are shown in table 5. In all three of the examined ages the highest mean density of oven-dry birch wood was noted in the thinnest trees. For the 30 and 70-year-old trees the value of the studied property is diminishing along with the increase in their thickness. In 50-year-old birch trees the average thickness of trees has a lower mean density than the thickest trees.

Table 4. Influence of the age of trees and the class of the thickness and interaction of these properties on the density of oven-dry wood (two factorial variance analysis)

Source of variance	Sum of squares	Degrees of freedom	Mean squares	F empirical	p-Value
Intercept	1914872852.6	1	1914872852.6	730185.6	< 0.0001 *
Age	1253797.6	2	626898.8	239.1	< 0.0001 *
Thickness class	149071.0	2	74535.5	28.4	< 0.0001 *
Age-Thickness class (interaction)	148175.6	4	37043.9	14.1	< 0.0001 *
Error	12503826.9	4768	2622.4		

*Statistically significant at the 0.05 level.

Table 5. Properties of the density of oven-dry wood of different ages and classes of the tree thickness

Age	Thickness class	Number of groups (N)	Mean	Standard deviation
30	1	484	614.74	50.10
	2	544	614.27	45.69
	3	543	608.13	50.44
50	1	526	645.07	60.88
	2	523	624.18	58.52
	3	534	639.98	50.72
70	1	537	664.65	46.42
	2	544	650.48	42.14
	3	542	640.20	53.61
Total		4777	633.70	54.27

In Forest Districts where the properties of the wood of birch trees in fresh broadleaved forest and fresh mixed broadleaved forest habitats were studied, the analysis of the relation between the oven-dry wood density and the location of the test plots and forest type habitat were carried out. It was proved that both factors together with the interactions between them generate statistically significant differences in the average values of density among the analysed groups (tab. 6).

Table 6. Influence of the location and the FHT (Forest Habitat Type) and interaction of these properties on the density of oven-dry wood (two factorial variance analysis)

Source of variance	Sum of squares	Degrees of freedom	Mean squares	F empirical	p-Value
Intercept	1117540030.9	1	1117540030.9	453566.5	< 0.0001 *
Location	378170.3	4	94542.6	38.4	< 0.0001 *
FHT	56044.5	1	56044.5	22.7	< 0.0001 *
Location-FHT (interactions)	294973.3	4	73743.3	29.9	< 0.0001 *
Error	6891512.8	2797	2463.9		

*Statistically significant at the 0.05 level.

Table 7 shows the results of the grouping of the test plot locations with the inclusion of FHT. Statistically significant differences among the mean densities in the examined forest habitat types exist in the Forest Districts of Giżycko, Łobez and Rudziniec. A Higher mean density of oven-dry wood was determined in the samples originating from trees that grew in the fresh mixed broadleaved forest habitat type forests in the Forest Districts of Giżycko, Lipinki and Rudziniec and decreased with the rise in the habitat's fertility in fresh broadleaved forest type habitats. In northwest Poland, in the Forest Districts of Bobolice and Łobez, completely opposite tendencies were observed. Together with the rise of habitat's fertility from FMBF to FBF the average values of wood density were increasing.

The issue of the oven-dry density of birch wood is not frequently raised. Furthermore, if it is mentioned in most cases the same records are repeated, i.e. the mean value is 610 kg/m^3. These values are quoted by: Kollmann [1951], Galewski and Korzeniowski [1958], Krzysik [1978], Surmiński [1979] and Wagenführ and Scheiber [2007]. In the literature only Trendelenburg and Mayer--Wegelin [1955] present different values regarding four locations: for Austria (q_0) is 671 kg/m^3, for Germany 655 kg/m^3 (Starnberg) and 600 kg/m^3 (Planegg), 2 locations nearby Munich, for Latvia 610 kg/m^3 and for Finland 600 kg/m^3.

Table 7. Homogeneous groups in terms of the average value of the oven-dry wood density shown for the location and FHT

Location	FHT	Mean	1	2	3	4	5	6
Łobez	FMBF	611.88	****					
Bobolice	FMBF	616.55	****	****				
Rudziniec	FBF	617.01	****	****				
Bobolice	FBF	621.41	****	****			****	
Lipinki	FBF	626.58		****	****		****	
Łobez	FBF	634.15			****	****	****	
Giżycko	FBF	636.39			****	****		
Lipinki	FMBF	637.24			****	****		
Rudziniec	FMBF	644.75				****		
Giżycko	FMBF	669.85						****

The mean density of oven-dry wood of silver birch for the entire examined material amounted to 633.7 kg/m^3. The lowest density of a single sample determined in the studied material was 460.0 kg/m^3, the highest – 816.7 kg/m^3. The average value of wood density for the entire tested material was higher by 13.7-33.7 kg/m^3 from the values shown by other authors. Vorreiter [1949] reports the mean density of oven-dry wood at the level of 600 kg/m^3; Kollmann [1951] – 610 (460–800) kg/m^3; Wanin [1953] – 620 kg/m^3; Galewski and Korzeniowski [1958] – 610 (460–800) kg/m^3; Kamiński and Laurow [1966] – 610 kg/m^3; Krzysik [1978] – 610 (460–800) kg/m^3; Wagenführ and Scheiber [2007] – 610 (460–800) kg/m^3.

Only Miler [1966] has reported a higher density of oven-dry wood of silver birch in Poland. The birch wood density calculated by him – 710 kg/m^3 at a 15% moisture content was higher than the average determined in this study. The wood for Miler's studies originated in the Forest District of Gniezno and had an average age of 52 years. Higher values of oven-dry density by 37 kg/m^3 were obtained in Austria and by 21 kg/m^3 in Starnberg (Germany) than the mean value obtained for the entire country of Poland. These values are similar to those obtained in the Forest Districts of Giżycko in FMBF (669,85 kg/m^3) and Sokołów in FBF (662.04 kg/m^3) located in the northeast of Poland.

The minimum values obtained in this study were identical, and maximum values were higher by 16.7 kg/m^3 than those cited by the other authors.

As a comparison, in this study, depending on the age, the following average values of density were obtained: for 30-year-old trees – 650.6 kg/m^3, 50-year-old – 671.9 kg/m^3 and for 70-year-old – 683.0 kg/m^3.

Conclusions

The following list of conclusions can be formed based on the analysis of the oven-dry silver birch wood density depending on the geographical location of the stands, the age of trees, the tree thickness, forest habitat type and the interactions between those factors:

1. The location, the age of trees, the tree thickness as well as forest habitat type and the interactions between those factors, had a considerable influence on the density of the oven-dry silver birch wood in Poland.
2. The highest average values of the completely dry birch wood were found in the wood in the Forest District of Giżycko in FMBF – 669.85 kg/m^3 and in Sokołów in FBF – 662.04 kg/m^3.
3. For the entire examined material, the average values of the oven-dry wood density rise together with age. In all three ages the highest average values of oven-dry wood density were observed in the thinnest trees.
4. With a few exceptions, the birch wood originating from the eastern parts of Poland displays higher average values of oven-dry wood density which, in turn, leads to an increase in carbon accumulation. This applies to 50 and 70--year-old birch stands.
5. It seems necessary to broaden the study of the variability of the birch wood density, in accordance with the methodology of this study, on to different forest habitat types. Such studies could significantly deepen the knowledge of the technical quality of birch wood in Poland.

References

Bijak Sz., Bronisz K., Szydłowska P., Wojtan R. [2014]: Wpływ jakości siedliska na dynamikę wydzielania brzozy na gruntach porolnych (Effect of site quality on self-thinning dynamics in silver birch stands on abandoned farmlands). Sylwan 158 [6]: 423--430

Bruchwald A. [1989]: Statystyka matematyczna dla leśników (Mathematical statistics for foresters). Wydawnictwo SGGW, Warszawa

Fabisiak E. [2005]: Zmienność podstawowych elementów anatomicznych i gęstości drewna wybranych gatunków drzew (Variation of fundamental anatomical elements and wood density of selected tree species). Roczniki Naukowe Akademii Rolniczej w Poznaniu, Rozprawy Naukowe 369: 1-176

Fabisiak E., Kocjan H. [2005]: Promieniowa zmienność parametrów makro- i mikrostrukturalnych drewna brzozy (*Betula verrucosa* Ehrh.) z uprawy plantacyjnej (Radial changeability of macro- and micro-structural parameters in birch wood (*Betula verrucosa* Ehrh.) from plantation). Roczniki AR Poznań, Technologia Drewna 40: 3-13

Forest Data Bank [2017] https://www.bdl.lasy.gov.pl/portal/t-en [accessed: 22.12.2017]

Galewski W., Korzeniowski A. [1958]: Atlas najważniejszych gatunków drewna (Atlas of the most important wood types). PWRiL, Warszawa

Grochowski J. [1973]. Dendrometria (Dendrometry). PWRiL, Warszawa

Hakkila P. [1966]: Investigations on the basic density of Finnish pine, spruce and birch wood. Communicationes Instituti Forestalis Fenniae 61 [5]: 1-98

Hakkila P. [1979]: Wood density survey and dry weight tables for pine, spruce and birch stems in Finland. Communicationes Instituti Forestalis Fenniae 96 [3]: 1-59

Helińska-Raczkowska L., Fabisiak E. [1995]: Zależność między długością elementów anatomicznych i gęstością drewna brzozy (*Betula pendula* Roth.) (Relation between the length of anatomical elements and the density of birch wood (*Betula pendula* Roth.)). Prace Komisji Technologii Drewna. PTPN 14: 43-48

Helińska-Raczkowska L. [1996]: Zmienność wilgotności i gęstości drewna w świeżo ściętych pniach brzozy (*Betula pendula* Roth.) (Wood moisture content and density variation in the freshly-filled birch (*Betula pendula* Roth.) stem). Folia Forestalia Polonica. Seria B 27: 23-30

Kala R. [2009]: Statystyka dla przyrodników (Statistics for naturalists). Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu, Poznań

Kamiński E., Laurow Z. [1966]: Główne użytkowanie lasu. 1. Nauka o surowcu drzewnym (Main function of the forest. Study of raw wood material). Wydawnictwo SGGW, Warszawa

Kokociński W. [2004]: Drewno. Pomiary właściwości fizycznych i mechanicznych (Wood. Measuring of physical and mechanical properties). Wydawnictwo – Drukarnia PRODRUK, Poznań

Kollmann F. [1951]: Technologie des holzes und der holzwerkstoffe. Springer – Verlag, Berlin, Göttingen, Heidelberg, J.F. Bergmann, München

Krzysik F. [1978]: Nauka o drewnie (Wood science). PWN, Warszawa

Lachowicz H. [2010a]: Struktura włókien drewna brzozy brodawkowatej (*Betula pendula* Roth.) w północno-wschodniej Polsce. Structure of silver birch wood fibers (*Betula pendula* Roth.) in north-eastern Poland. Leśne Prace Badawcze 71 [1]: 39-50

Lachowicz H. [2010b]: Wybrane wskaźniki jakości technicznej drewna brzozy brodawkowatej (*Betula pendula* Roth.) w północno-wschodniej Polsce (Selected indicators of technical quality of silver birch (*Betula pendula* Roth.) wood in north-eastern Poland). Leśne Prace Badawcze 71 [2]: 135-147

Lachowicz H., Jednoralski G., Paschalis-Jakubowicz P. [2014]: Wpływ siedliska na wybrane właściwości strukturalne i fizyko-mechaniczne drewna brzozy brodawkowatej (*Betula pendula* Roth.) (Effect of habitat on the selected structural and physico-mechanical properties of silver birch (*Betula pendula* Roth.) wood). Sylwan 158 [4]: 285-291

Lachowicz H., Paschalis-Jakubowicz P. [2014]: Impact of a fresh broadleaved forest site and fresh mixed broadleaved forest site on selected parameters and ratios of silver birch (*Betula pendula* Roth.) wood fibre structure (Wpływ siedliska lasu świeżego i lasu mieszanego świeżego na wartości wybranych parametrów i wskaźników struktury włókien drewna brzozy brodawkowatej (*Betula pendula* Roth.)). Drewno 57 [193]: 109-117. DOI: 10.12841/wood.1644-3985.056.07

Lachowicz H. [2015a]: Wieloczynnikowa analiza jakości technicznej drewna brzozy brodawkowatej (*Betula pendula* Roth.) w Polsce (Multivariate analysis of the selected technical quality indicators in silver birch (*Betula pendula* Roth.) wood). Temat badawczy finansowany przez Dyrekcję Generalną Lasów Państwowych. Katedra Użytkowania Lasu SGGW, Warszawa

Lachowicz H. [2015b]: Wieloczynnikowa analiza zmienności wybranych właściwości strukturalnych, fizycznych i mechanicznych drewna brzozy brodawkowatej (*Betula pendula* Roth.) (Multivariate analysis of the variation of structural, physical and mechanical properties of silver birch (*Betula pendula* Roth.) wood). Rozprawy Naukowe i Monografie. Wydawnictwo SGGW, Warszawa: 153

Miler Z. [1961]: Badania własności technicznych drewna brzozy brodawkowatej i omszonej – *Betula verruccosa* Ehrh. i *Betula pubescens* Ehrh (Study of the technical properties of silver *Betula verruccosa* Ehrh. and downy *Betula pubescens* Ehrh birch wood). Rozprawa doktorska. Akademia Rolnicza, Poznań [PhD thesis]

Miler Z. [1966]: Badania nad własnościami drewna brzozy brodawkowatej i omszonej (Study of the technical properties of silver *Betula verruccosa* Ehrh. and downy *Betula pubescens* Ehrh birch wood). Folia Forestalia Polonica, Seria B 7: 135-159

Möttönen V., Luostarinen K. [2006]: Variation in density and shrinkage of birch (*Betula pendula* Roth.) timber from plantations and naturally regenerated forests. Forest Products Journal 56 [1]: 34-39

Repola J. [2006]: Models for wertical wood density of Scots pine, Norway spruce and birch stems, and their application to determine average wood density. Silva Fennica 40 [4]: 673-685

Stanisz A. [2006]: Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny (Accessible course in statistics with STATISTICA PL application on examples from medicine). t. 1 3. StatSoft Polska Sp.z o.o., Kraków

Surmiński J. [1979]: Właściwości techniczne drewna brzozy i możliwości jego użytkowania (Technical properties of birch wood and possibilities of its utilization). In: Brzozy (Birches). PWN, Warszawa Poznań

Trendelenburg R., Mayer-Wegelin H. [1955]: Das Holz als Rohstoff. Carl Hanser Verlag München

Tomczk A., Jelonek T. [2012]: Parametry techniczne młodocianego i dojrzałego drewna sosny zwyczajnej (*Pinus sylvestris* L.) (Technical parameters of juvenile and mature wood in Scots pine (*Pinus sylvestris* L.)). Sylwan 156 [9]: 695-702

Vorreiter L. [1949]: Holztechnologisches Handbuch. Band I: Allgemeines, Holzkunde, Holzschutz und Holzvergütung. Verlag Georg Fromme & Co., Wien

Wagenführ R., Scheiber Chr. [2007]: Holzatlas. Leipzig, VEB Fachbuchverlag

Wąsik R., Michalec K., Barszcz A. [2015]: The variability of certain macrostructural features and the density of grand fir (*Abies grandis* Lindl) wood from selected stands in southern Poland. Drewno 58 [195]: 45-58. DOI: 10.12841/wood.1644-3985.118.04

Wanin S. [1953]: Nauka o drewnie (Wood science). PWRiL, Warszawa

Wroniszewska P. [2015]: Rozkład gęstości w średniowymiarowym i wielkowymiarowym drewnie brzozy brodawkowatej (*Betula pendula* Roth.) (Density distribution in middle – sized and large – sized silver birch (*Betula pendula* Roth.) wood). Praca doktorska. SGGW, Warszawa [PhD thesis]

Zasada M., Bijak Sz., Bronisz K., Bronisz A., Gawęda T. [2014]: Biomass dynamics in young silver birch stands on post-agricultural lands in central Poland. Drewno 57 [192]: 29-39. DOI: 10.12841/wood.1644-3985.S07.02

List of standards

PN-77/D-04100 Drewno. Oznaczanie wilgotności (Wood. Determination of moisture content)

PN-77/D-04101 Drewno. Oznaczanie gęstości (Wood. Determination of the density)

PN-77/D-04227 Drewno. Ogólne wytyczne pobierania i przygotowania próbek (Wood. Methods of sampling)

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